

# Design and Simulation of a High Isolation Single-Balanced Mixer

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**Abstract.** A single-balanced mixer is designed by using the Agilent ADS software. Bat15-03w diodes(Infineon) are used and the insert loss is less than 1.4dB. The conversion loss is no more than -19.5dB and noise figure is lower than 10dB, when the RF frequency is 2.4GHz and the LO frequency is 2.3 GHz. The PCB model is built and tested with ideal results.

## 1.Introduction

With the development of microwave communication techniques, the quality and efficiency of the communication device become more and more important. As an absolutely necessary part of the microwave system, mixer is supposed to be low noise and smart in size.

## 2.Theory and Design

### A. Theory

The function of mixer is to transfer received RF signals to IF signals, then amplify them in the IF amplifiers. The structure of the single-balanced mixer is shown in Fig.1, which consists of a 3dB directional coupler, a match network, a nonlinear component and a low-pass filter. RF signal and LO signal are transferred to diodes via the 3dB directional coupler. Because of the nonlinear feature of the diode, the output consist of IF signal and the other harmonic waves. Then after the low-pass filter, in theory, the output is the IF signal desired.

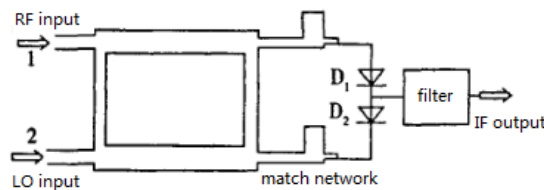


Fig.1 Structure of the Singled-Balanced Mixer

Passive diodes are used as nonlinear devices. At the frequency of microwave and millimeter wave, Schottky diode is widely used to a large extent. The virtues include simple circuit, convenience to be designed and integrated, stability, together with the wide bandwidth. When RF and LO signals come into port 1 and port 2 respectively, initial phases are both  $0^\circ$ . Considering that the same routes have no effect on relative phase, via the directional coupler, voltages on diode 1 and diode 2 are respectively as following:

$$V_{s1} = V_s \cos(\omega_{st} - \frac{\pi}{2}). \quad (1)$$

$$V_{L1} = V_s \cos(\omega_{Lt} - \pi). \quad (2)$$

$$V_{s2} = V_s \cos(w_{st}). \quad (3)$$

$$V_{L2} = V_s \cos(w_{Lt} + \frac{\pi}{2}). \quad (4)$$

From general calculate equation of mixed current, given the difference between LO current and that of RF, the mixed current in diode 1 and diode 2 is,

$$i_1(t) = \sum_{n,m=-\infty}^{\infty} L_{mn} \exp \left[ jm \left( w_{st} - \frac{\pi}{2} \right) + jn(w_{Lt} - \pi) \right]. \quad (5)$$

Similarly, the current in diodes 2 is,

$$i_2(t) = \sum_{n,m=-\infty}^{\infty} L_{mn} \exp \left[ jm(w_{st}) + jn \left( w_{Lt} + \frac{\pi}{2} \right) \right]. \quad (6)$$

When  $m=\pm 1$ ,  $n=\pm 1$ , considering that  $I_{-1,+1} = I_{+1,-1}$ , the IF current is:

$$i_{IF} = 4|I_{-1,+1}| \cos[(w_{Lt} - w_{st}) + \frac{\pi}{2}]. \quad (7)$$

## B. Design Progress

The 3dB directional couplers are composed of main line, second line and two branch lines. The length of the branch line is shown in Fig. 2 .

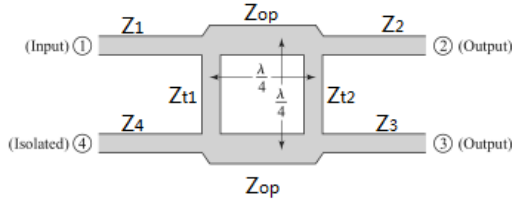


Fig.2 3dB directional coupler

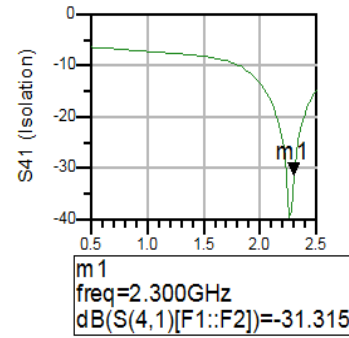


Fig.3 Isolation between port1 and port 4

Suppose that  $Z_1 = Z_0$ ,  $Z_2 = Z_{0k}$  ( $k$  is the resistance change ratio),  $Z_3 = Z_{0k}$ ,  $Z_4 = Z_0$ , the characteristic impedance of parallel connect line is  $Z_{0k}$ , and characteristic impedances of branch lines are  $Z_{t1}$  and  $Z_{t2}$ , respectively.

Using the microstrip calculation tool in ADS, LineCal, the width of microstrip line on FR4 substrate are 1.39 millimeters and 3.07 millimeters respectively for  $50\Omega$  and  $30\Omega$ . For the requirement of isolation, 3dB power and  $90^\circ$  phase-difference, set the optimize goal and optimize in ADS. The simulation result is shown in Fig.3. It's shown that isolation between port 1 and port 2 is -31.315dB.

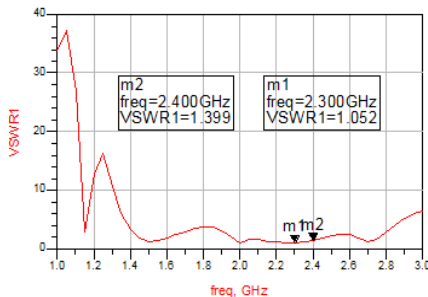


Fig.4 VSWR of the Input Port

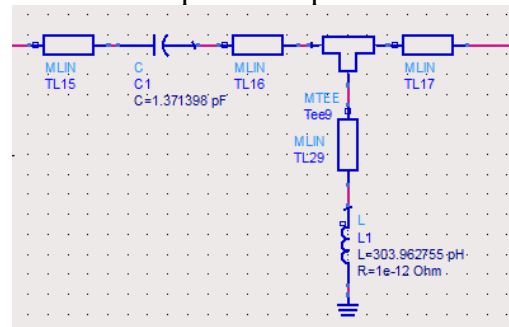


Fig.5 Impedance of match network

Using Smith Chart, after calculation of the output impedance of the coupler, we can design the impedance match network with integrated device named inductance and capacitance. With the tool

of Smith Chart, the structure and parameters of match network come out easily. For one class series-parallel structure of capacitance and inductance, it can be seen as a band-pass filter with narrow band-width. So match network can also be treated as a filter that can let IF signals pass.

### 3.Simulation Results

In general, circuit network includes linear sub-network and nonlinear sub-network, among which, the frequency of linear sub-network can be described by frequency algebra equation, while nonlinear sub-network can be described by time domain nonlinear equation. It is the method of choice for simulating analog RF and microwave problems, since these are most naturally handled in the frequency domain. In the context of high-frequency circuit and system simulation, harmonic balance offers several benefits over conventional time-domain transient analysis. The frequency integration required for transient analysis is prohibitive in many practical cases. Many linear models are well represented in the frequency domain at high frequencies.

The setting for the variables is shown in Fig. 6 and each harmonics components of the IF output is shown in Fig.7.

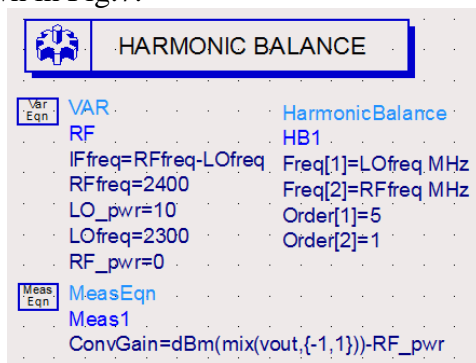


Fig.6 Variables of the circuits

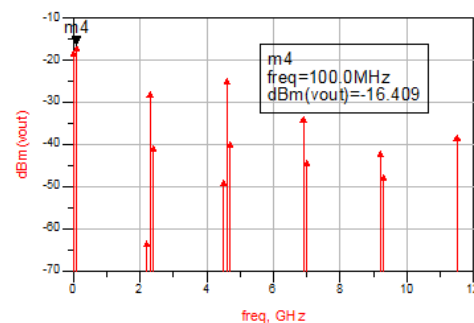


Fig.7 Components of the Harmonic

As can be seen from Fig.7, there are many frequency components. For RF is 2.4GHz, LO is 2.3GHz, the IF signal is 100MHz, and the 100MHz signal just in Fig.7. It shows that this simulation of mixer is right. And with parameter sweep, maximum power of IF is -37.87dBm when LO power is 7dBm. In some range, conversion loss become smaller with LO power's increase.

The whole circuit is designed and simulated by the Agilent ADS software. When parameters of the circuit are not ideal, the optimize tool in the software can modify until parameters become desirable, before make PCB in Altium Designer software.

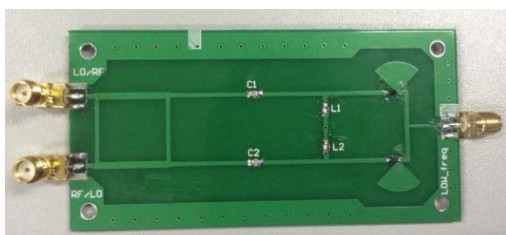


Fig.8 PCB of the Mixer

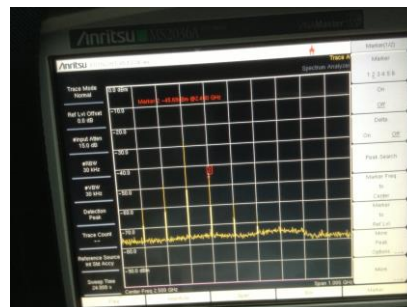


Fig.9 Results of VNA

According to the circuit diagram, PCB view is shown as Fig.8. The board size is  $5 \times 10 \text{ cm}^2$ . After welding the components, the circuit is measured by a VNA (vector network analyzer) shown in Fig.9 and a high frequency active signal source with the RF input signal is 5dBm, and the LO signal is 0dBm. It tuned out that the output IF signal is 100MHz, -28dBm, conversion loss is 9.12 dB, matching well with simulation result, without frequency deviation.

#### **4.Summary**

A passive single-balanced down conversion mixer is designed, and the main parts are 3dB directional coupler, match network of output and two diodes. The simulation of the 3dB directional coupler and output match network is introduced, together with the analysis of the basic parameters of the mixer and a PCB design. The measured technical parameters fulfill the requirements in practice.

#### **References**

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